N76-19455

APPLICATIONS WORKSHOP III-B-4

MANUFACTURING PROCESSES

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Gerald Zimmerman (Hamilton);
J. P. Myers (SL); W. D. Jones (SL); E. D. Roth (SL)

B. S. Gardiner began the workshop with the following presentation, describing Sandia's shop techniques.

SANDIA PROCESS FOR MAKING PRECISION ROLAMITE

The Sandia shop is primarily responsible for the fabrication of bands, fabrication of contacts or any part that would have to be etched, and the assembly of all parts, as well as the directing of the fabrication for such parts as rollers and cases. We put orders on other shops, and follow the proper inspection. We make complete assemblies. Then we test the units through all environments on test equipment we designed.

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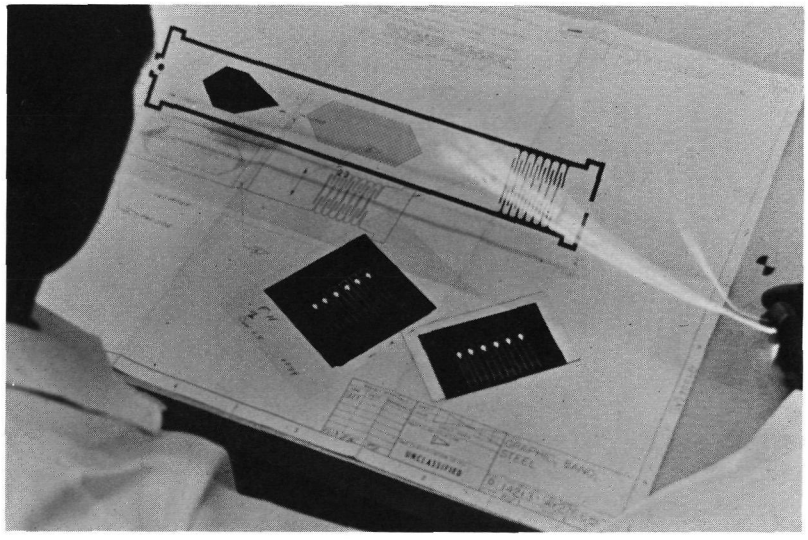

Figure 1. The Gerber Plotter, 10-to-1 Master

PHOTOMASTER

The plotter is on 7-mil Mylar, a 10-to-1 of the first band used. I'll refer to this as the MC2471, a 5G rolamite. The smaller multiple is a Mylar multiple; the one on the right is glass. We are going more to the glass; we can get more stability and have fewer problems with heat.

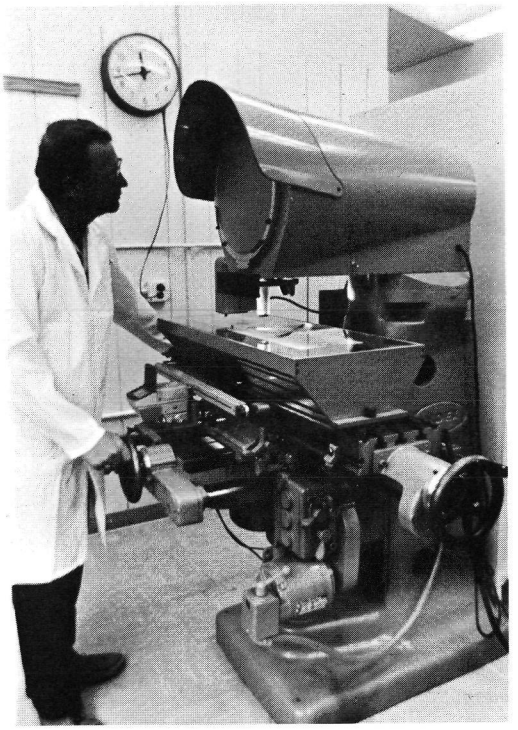

Figure 2. A Converted Index Mill Base Optical Comparator

A converted index mill base gives us a travel range of about 24 by 12 inches, so that we can accurately analyze the condition of the master before having photo reduction. All measurements are on direct reading instruments with the possibility of error quite low. We hold our 10-to-1 masters to within 1 mil and we reduce down to 1/10 mil, holding all tolerances in all directions to 1/10 mil. Because we go from the Gerber plotter to a photo reduction system we will have a little accumulated error, but we are within 2/10 of a mil on our final negative that we will be using for processing.

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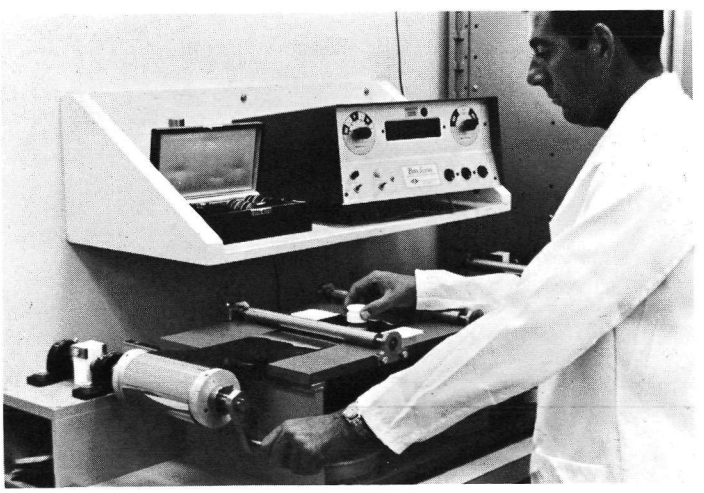

Figure 3. Betascope

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We start off by measuring the materials that we are going to use. In this case, because we are generally less than 2 mils in thickness, we use the Betascope. The Betascope is better in the low thickness measurement ranges. To get above the few mil range you must go to X-ray or direct mechanical measurements. We will be able to get down to a few millionths of an inch accuracy measurements. We can crank rolls of material through this table.

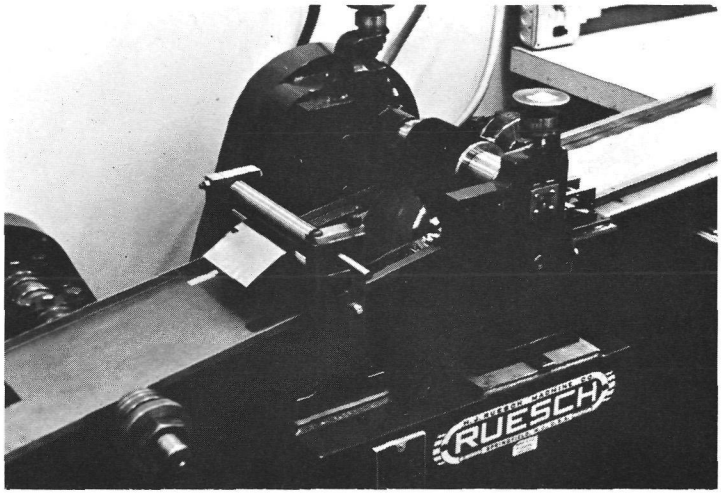

Figure 4.
Slitter

BAND MATERIAL PROCESSING

The slitter is used to cut the width of material for laminating. It is rare that we would use the slitter for separation of bands from the multiple etching pattern. It is used for getting a good, true, accurate edge for laying up laminates. We have slit materials as thin as 3/10 of a mil in stainless. We have to back up thin materials with paper or some other material. We can go up to 10 mils in thickness on this piece of equipment and hold the width accuracy to 2/10 mil.

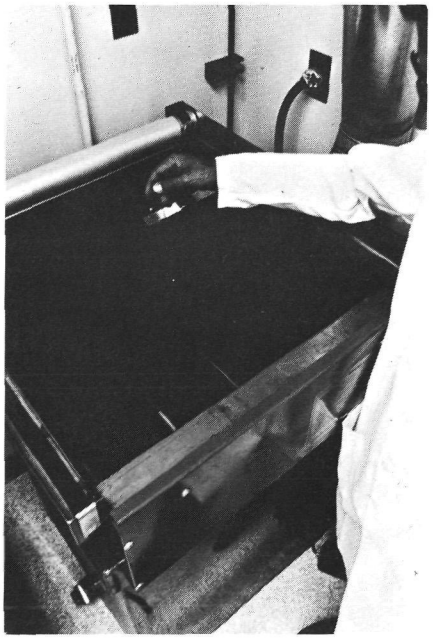

Figure 5.
Vapor Degreaser

We must make sure the material is thoroughly clean; vapor degreasing is one of the methods; we also use ultrasonic cleaners.

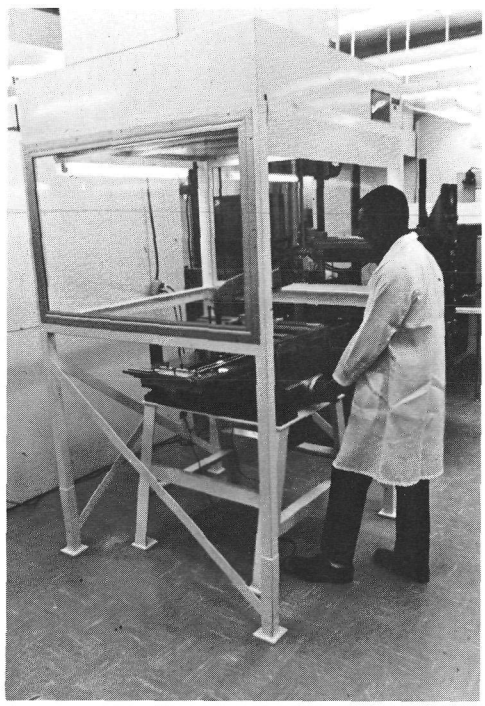

Figure 6. Laminant Lay-Up Table, View A

We use a laminar down-flow cage to make sure the dust and dirt particles are kept off the laminants while we are laying them up.

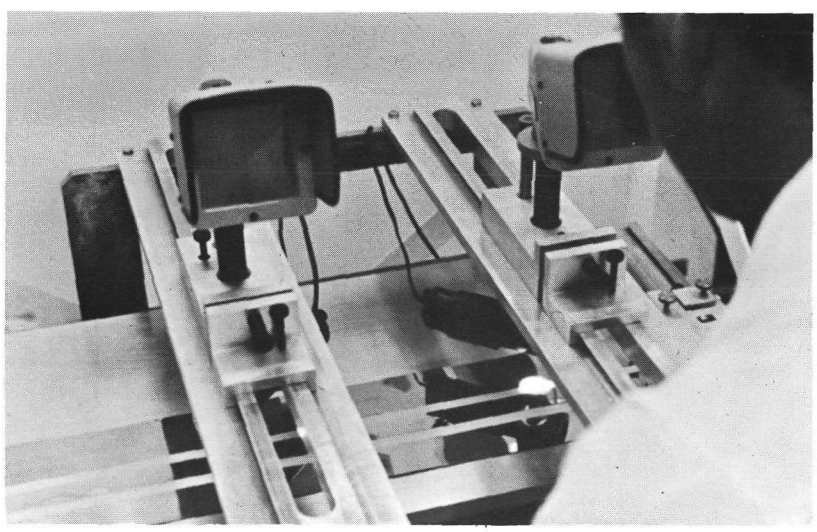

Figure 7. Laminant Lay-Up Table, View B

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Figure 7 shows a better view of what we are trying to do. We have, in this case, 5-mil beryllium copper with 2-mil adhesive Mylar, and on top of it we have 1-mil beryllium copper. Two optic systems are used to reduce the amount of travel to cross the table. The two optic systems will normally be lined up with each other.

Figure 8. Press

Once we have the materials laid up as we need them on the laminant lay-up table, we can remove the whole table top, put a cover plate over it without removing the material from that table top, and insert the top into the press. The press is capable of about 15 tons on a 6-inch ram. We can heat the platens to a temperature of 600 degrees for any time that we desire, so that we can properly make a good, secure laminant.

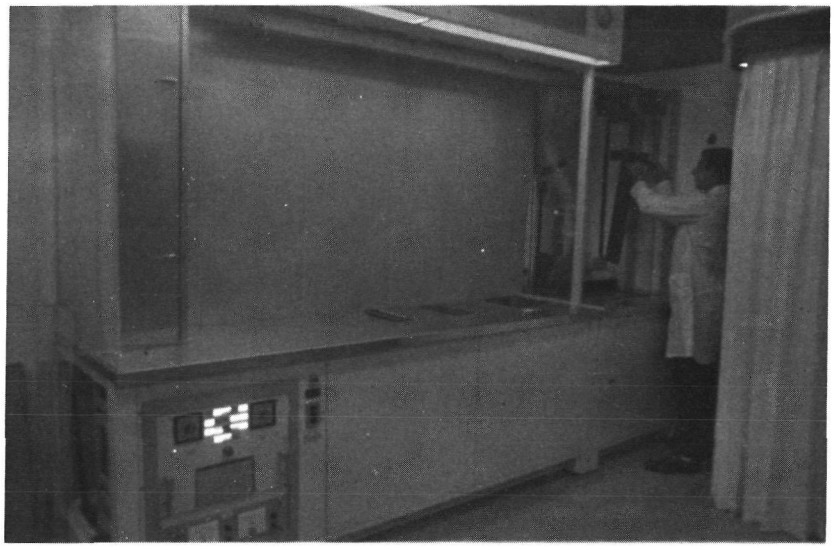

Figure 9. Exposure and Cleaning Area

PHOTO ETCHING

This is the yellow light area, where we do the exposing of the resist-coated materials and where we clean the materials and develop the exposed pattern. A laminar outflow bench is conveyerized and is driven by the control panel. By programming the drum properly we do scrubbing, rinsing, and resisting operations in very controlled conditions at very controlled rates. We went to a vertical resisting method, and a vertical scrubbing method, to conserve space. For horizontal systems we need much larger facilities. The right-hand tank where the conveyer system is being loaded is a detergent abrasive wheel scrubber tank. The next tank is a rinse tank, using tap water as a rinse and soft brushes for removing the detergents. The next three tanks can contain any combination of solutions. We use a couple of deionized water rinses and a light nitric acid solution followed by a final deionized water rinse. The open tank in the middle is an oven. We can get up to about 300°F to dry the materials before resist-coating, and to cure the resist after we have resist-coated. The small tank, to the left, is the resist. We use a positive resist. We extract at a controlled rate to get a uniform thickness of the resist on the material. After we have resist-coated, we move over to the oven and bake for 15 minutes to make sure that the resist is dried. We have thought about speeding up the drying time of the resist with infrared light.

Here we use the multiple negative method of exposing the resist-coated material. We can expose from either side with this system. We have found that the exposure times are approximately 1 minute and 15 seconds. The thickness of the resist is about 1/10 mil.

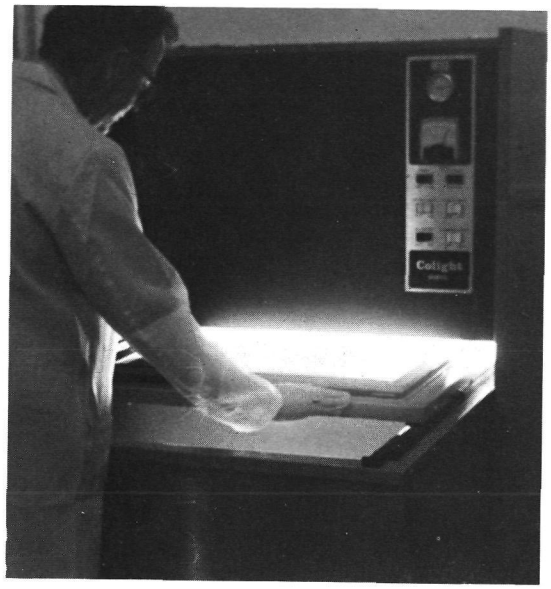

Figure 10. Colite Mercury Lamp Exposure System

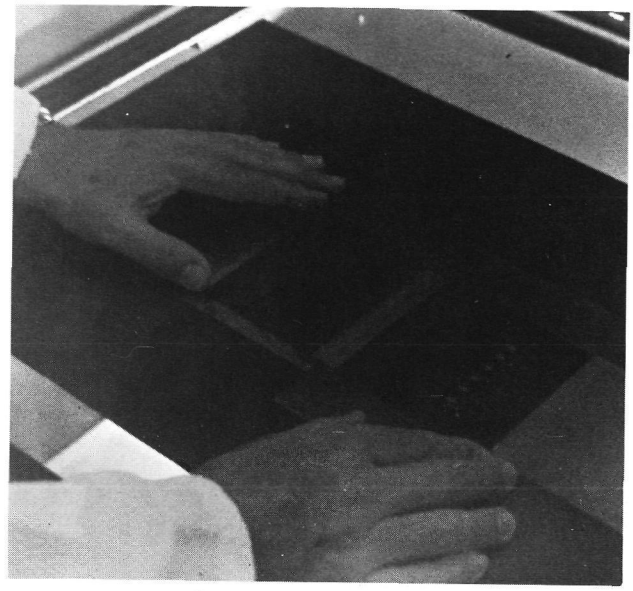

Figure 11. Close-Up of Colite System

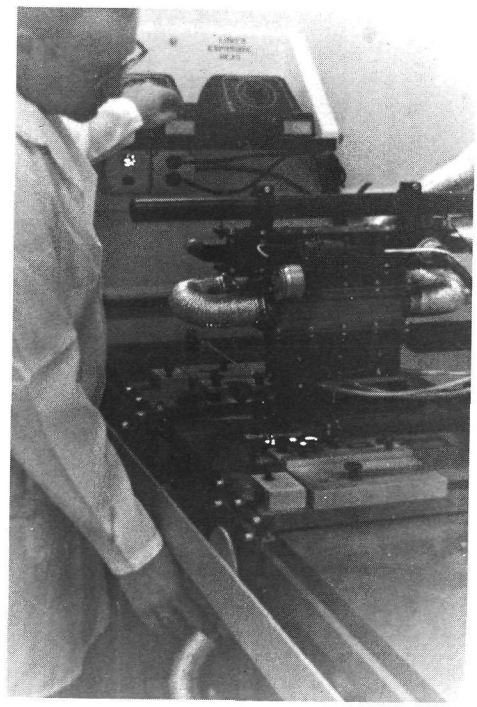

Figure 12. Step-and-Repeat Exposure Table

The table itself is moved by an air motor drive, with a detent rack underneath the table. There are two exposure heads, one above and one below the table. The heads are air-cooled. There is a 750-watt mercury lamp in the top of each head. The small hoses on the right are for holding negatives very closely to the material so that we do not have any flare from the negatives' separation. The two instruments at the upper

left are densitometers. They will accurately control the amount of exposure on each band. One advantage of this system is that we can detent and we can register. We can always go back to a given spot and re-expose if we have to, as in the case of laminants. We may have to expose several times. We are using, in this case, not the multiple negative but a single negative that is extremely accurate--one that we select from a batch of negatives and one that we know is accurate.

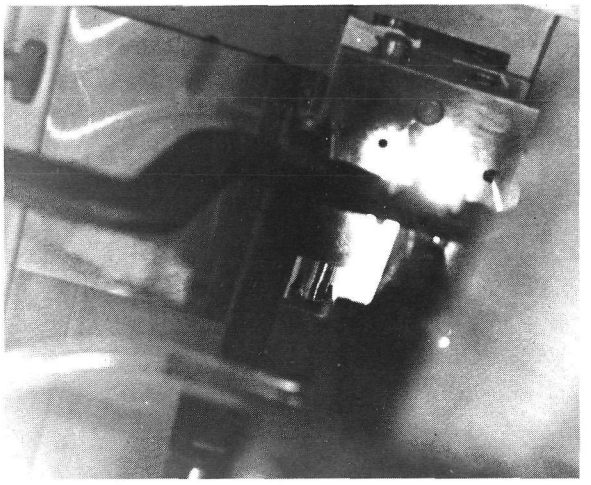

Figure 13. Location of Negative in System

We can reproduce bands very accurately without selecting one out of a batch. The system is very repeatable. In the case of the MC2471 band of 1-mil-thick stainless, we are asked to hold 1/2 mil on the length and 1/2 mil on the force cutout.

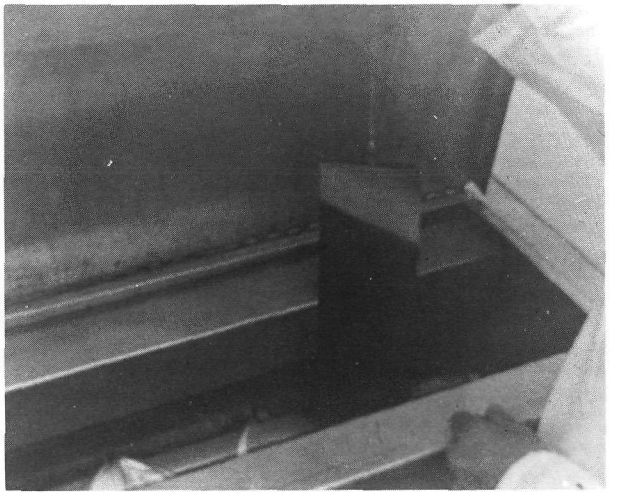

Figure 14. Spray Developing the Positive Resist

We hang the material in the tank, which is about 3 feet deep, and get a good spray-and-wash action.

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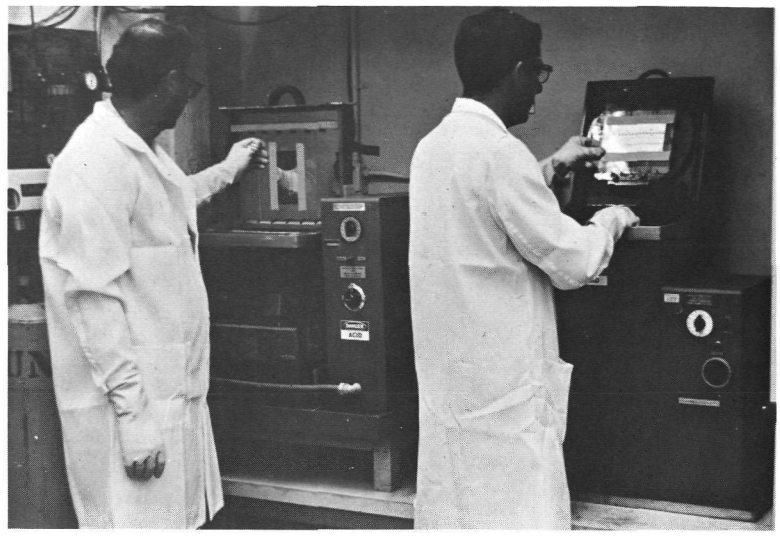

Figure 15. Etching Room

These two small etchers are used for developing the processes. The revolving etcher on the right holds the work horizontally. The spray is vertical in the bottom of the tank. The etcher on the left is vertical work with spray-etching from the front or back. For single-sided etchings we put a plastic plate in the frame.

Figure 16. Large Etchers

The larger etchers prove the ability of the system to produce. Once we devise the process for etching we are going to the big etchers and come out with methods that are suitable for production of any quantity of rolamite bands. In this case we have to support the material in a frame. We may have to go to the basket but now we use the frame of Fiberglas phenolic to support the long strips of material that run through the etching tanks. They come out on the right side completely rinsed.

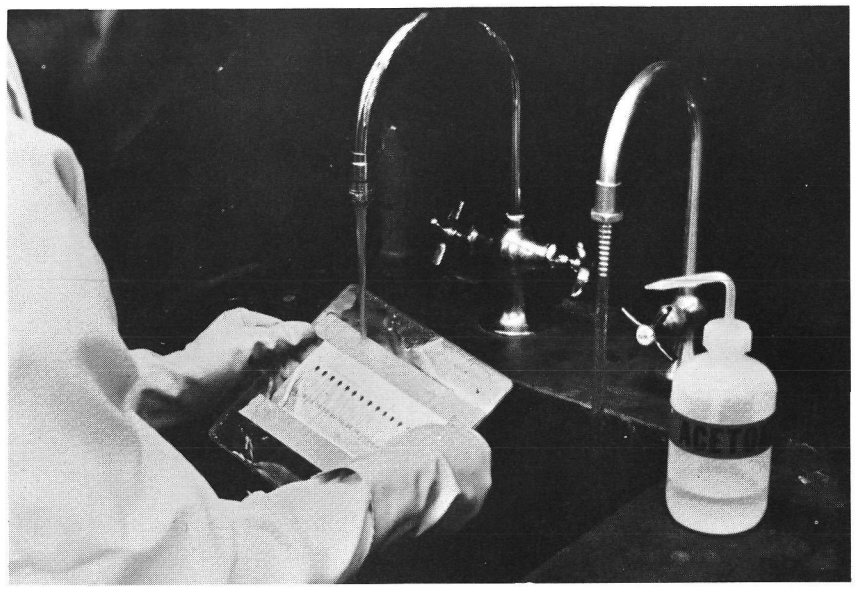

Figure 17. Removing the Resist

We wash off the remaining etching solution and then strip the resist with acetone. It is a very clean process--perhaps a little bit cleaner than the negative process that many of the printed-circuit shops are using.

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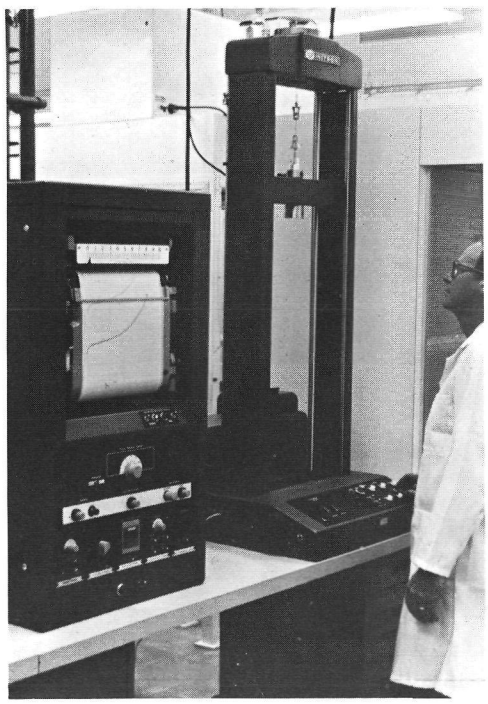

Figure 18. Instron Machine

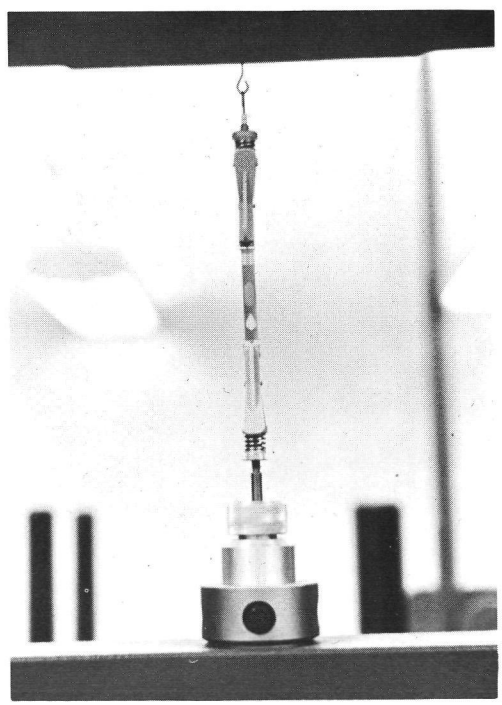

Figure 19. Close-Up of Tested Band

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BAND PROPERTIES -- MEASUREMENT

The Instron machine was used to a large extent in developing some of the technical data presented yesterday. Here we show a rolamite band. The rolamite band is suspended between the jaws of the Instron machine. We are actually stretching the band. We have an etched spring portion in the band. The top portion is an etched spring pattern. This spring holds the rollers in the proper geometry in a rolamite assembly, and we are measuring the force in that spring. We have an 18-gram deflection with about a 0.050-inch pull on the band itself. We will be able to measure the friction we have left in the systems.

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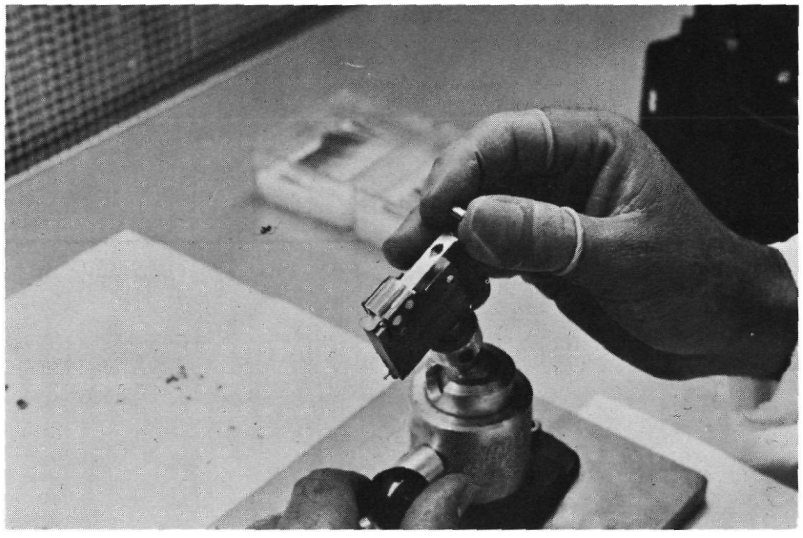

Figure 20. Assembly of the MC2471

ASSEMBLY

The parts are caps and extra bands and contacts. We are using a "third hand" assembly fixture. The rollers have a tendency to fly out. We use the "third hand" fixturing to avoid that problem. All our assembly is done on the laminar flow bench to keep the system as clean as possible.

* * *

FINISHED DEVICE

Figure 21 shows the triangular force cutout in the top of the case. The rollers are stainless steel, the end caps are made of polysulfone, and the case is glass. The cylindrical glass is shrunk around a tungsten mandrel to get the correct configuration holding the proper ramp angles in the corner and proper dimensions across all parts of the case. We have used glass for cases quite extensively.

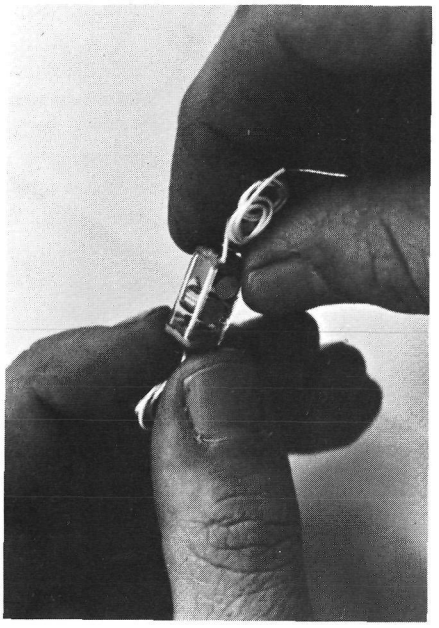

Figure 21.
Finished MC2471

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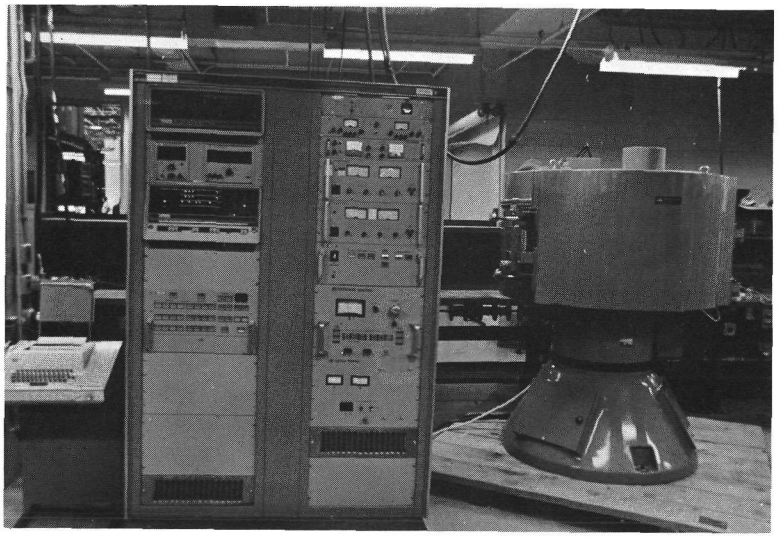

Figure 22. Test Equipment Designed by Glenn Elliott

DEVICE TESTING

The teletype input computer is a digital PBP-8. The system on the left is the main frame. On the right is the manual control of the centrifuge and centrifuge controlled mechanism.

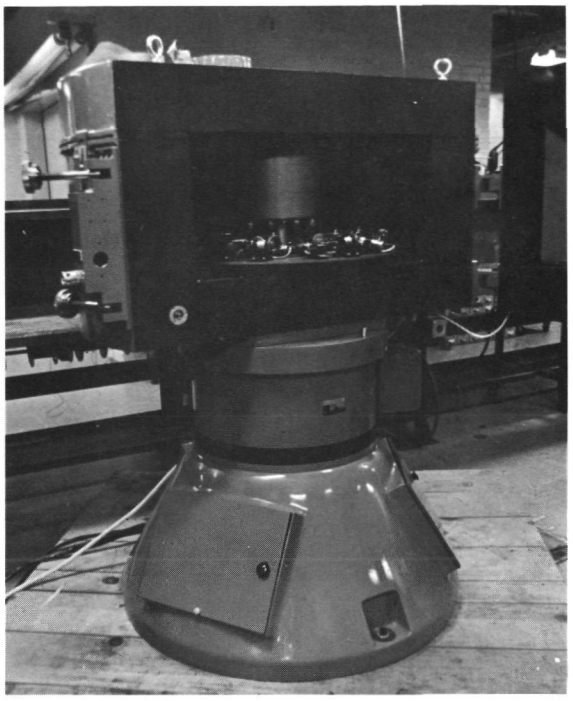

Figure 23.
Test Centrifuge

The centrifuge in Figure 23 shows the fixture for holding the MC2471 during test. The table has eight stations plus two setting stations.

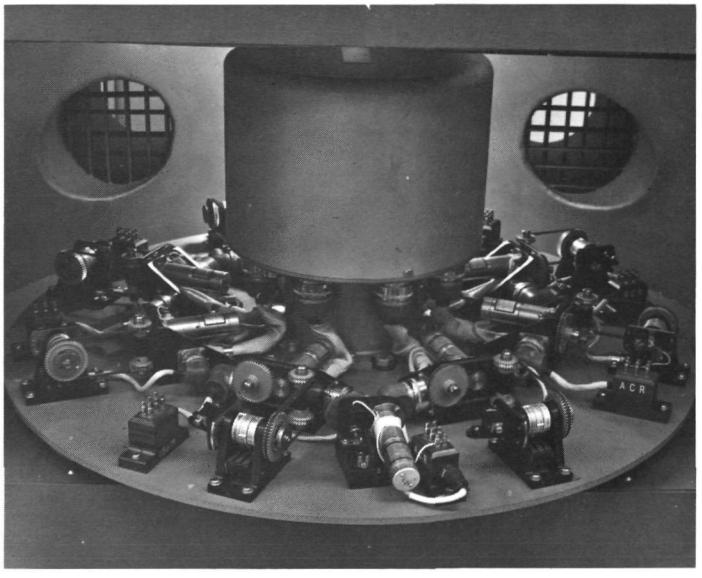

Figure 24.
Close-Up of Fixture

The flexible drive mechanism allows us to rotate the fixture 180 degrees for the reset position or the actuate position.

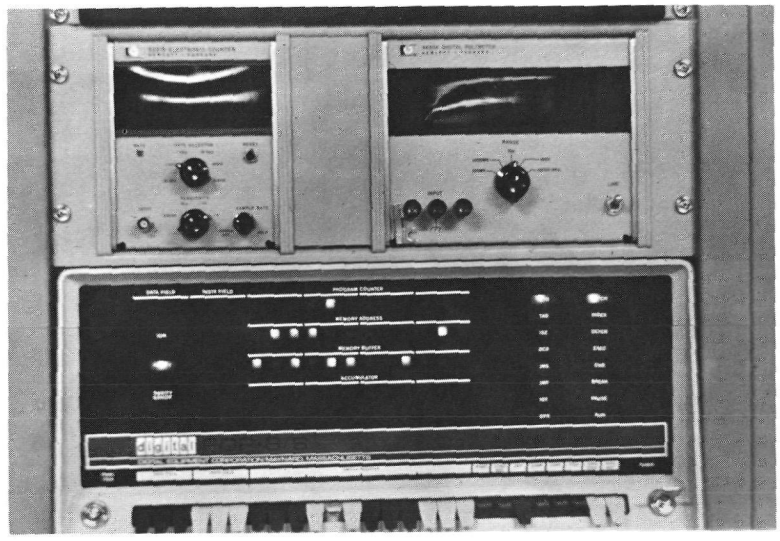

Figure 25. PDP-8/S Computer

The upper equipment is used for measuring contact resistance, g levels, and hi-pot values.

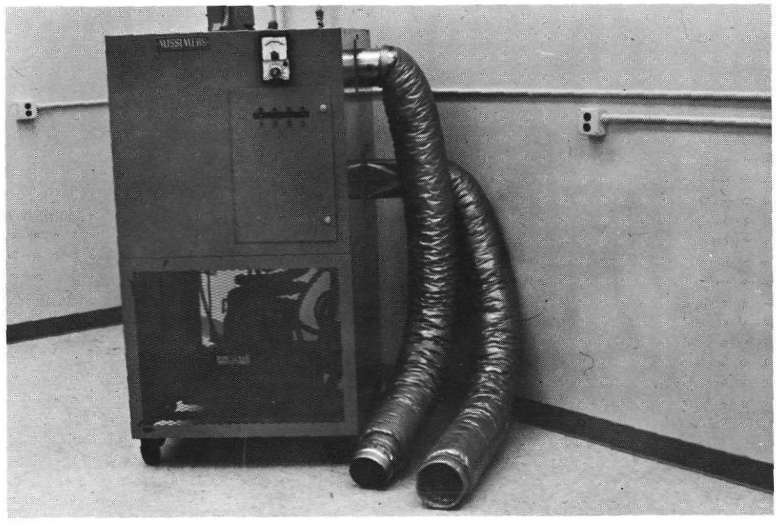

Figure 26. Environmental Cycling Chamber

This chamber allows us to go from a minus 100 to a plus 500 degrees F within the centrifuge chamber itself. It is independently operated.

We also use two thermal shock chambers. One is set at high level, the other at low level, and we transfer the material from one chamber to the other for thermal shock and then go back to the test equipment and test again. Other shock tests and vibration tests are run on the units, but other organizations are responsible for that type of testing.

PROPERTY MEASUREMENTS

Discussion in the workshop began with the problem of measuring extremely small tolerances in sealed assemblies.

E. D. Roth described Sandia techniques:

"Building cases out of four pieces is better than attempting to inspect a one-piece case before assembly occurs. We have found that by using a grazing incidence interferometer we can turn the usual microferometer into a macro-interferometer, and by using a grazing incidence angle of about 5-3/4 degrees and looking down one wall of the case we can get fringe separation using mercury lights that are about a hundred millionths apart. If we have an angle that perhaps is 400 millionths high, 15 mils wide down the side of the case, we will have those four fringes bent around the side; you count the fringes across and know the height of the angle.

"Another way of inspecting is to modify a Clevite gage, which can be done. You can put a tilt tip on the end of the gage and actually go right into the corner within 1/2 mil of the corner of the case."

* * *

FINISHED DEVICES FOR HIGH PRESSURE

EPOXIES FOR SEALING CASES

A participant whose application required high pressure inside the rolamite inquired about methods for holding the ends of the bands and sealing the case. In Sandia's development of the MC2471, the ends of the bands are tabbed to hook over the ends of the case. The end cap is sealed to the glass and the band with a silastic material. With variation of temperature the problem is more complex--the epoxy must expand and contract uniformly with the case, whether it be glass or whatever. Most of the hard epoxies have a different coefficient than glass. The first Sandia models had a rigid epoxy in the cases under different environments. In vibrations especially, the cases cracked, since there was no give between the polyurethane ends and the glass. Going to silastic has created some other problems--it is not rigid enough.

The sealing problem is complicated even further when electrical contacts are required.

* * *

TOLERANCE PRODUCTION OF CASES

Sandia arrived at four-piece case construction because of requirements for stainless-steel cases that were a few tenths in geometry. Making the cases out of four pieces allows preinspection of each piece before they are put together. This device fits on a surface plate with jaws perpendicular to the surface plate within 50 millionths. The case is assembled over a mandrel which can be adjusted in size. The four-piece case can be epoxied, soldered or welded. However, Sandia finds it very difficult to make a confidence-type inspection for pressure.

* * *

CASE PRODUCTION--TOLERANCES AND COST

At this juncture, W. D. Jones addressed the following remarks to the workshop in general:

"It is evident that Sandia is working with very, very close tolerances. We are spending a great deal of engineering time and production time and money to work to 1/10 percent in the cases, and I think it is important--especially if you are in a nonmilitary, commercial endeavor--that this degree of high precision does not deter you in your creative efforts of finding application for rolamites. The cost of making them is naturally important. With sufficient creativity on your part you will find, in most instances, economical applications of the rolamite principle. Take the case manufacture as an example; of necessity, we have had to work with the most exotic and expensive manufacturing processes. We have worked with electroform. It takes about 24 hours to form a case which would be equivalent to what we have assembled here in stainless steel, and it wouldn't be stainless steel--it would be nickel, which is hard to machine. Here it would be expensive without a doubt. How many of these cases we can get off of a given mandrel when we are electroforming them is problematic. Frankly, at this point, we would be lucky to get as many as 10 cases off of a mandrel before we would have to scrap it out. Mandrels may cost anywhere from $100 to $200 apiece.

ELECTROFORM CASES

GLASS CASES

One case per 24 hours is out of the question. The glass cases are made by vacuum shrinking under heat around tubular pieces over graphite-coated mandrels. If it is a complex shape it may take as many as five preforms. The simplest thing to vacuum-form would be a circle. The next simplest would be an oval, and then we get down to squares and non-square rectangles; if you have multirectangles you are taking perhaps 2-1/2 or 3 hours just to make the case, and then there is inspection time. Once you have your broaching machine, the broaching could be done for pennies in high production, and you could probably hold safely to plus or minus 1000, maybe a little less. But on the type of configurations we are talking about, probably plus or minus 1000 would be a practical tolerance in the broach chain. You may not even have to broach. You could buy commercial drum brass tubing either to size or design the product so that you merely run a sizing mandrel through the blanks and cut, baloney fashion, from your commercial brass tubing. Extruded cases can be automated so that actually you hardly touch the cases--with tubing and baloney style cutting each gets sized and comes out a complete case, plus or minus 1/1000 of an inch. The point I am trying to get at is this--I know that the rolamite units can be made for very competitive costs, can compete very well. "As for commercial hardware, rollers can be made for virtually nothing on screw machines; bands can be made in lattices 100 or 200 at a time by chemical milling."

BROACHED CASES

EXTRUDED CASES

* * *

HIGH QUALITY LOW COST ROLLERS

J. P. Myers added to the discussion of commercial casting of rolamite hardware, "I feel you might be able to make six rollers out of a $1.50 gage pin all the same size. I think that would be perhaps a better approach. Let's assume, to begin with, that we need a 3-to-5 microinch finish on the OD of rollers and we need roundness within millionths and we need a tolerance of 10ths of a mil. If you don't need quite as good a finish, if you can stand a little out-of-roundness and so forth, you can get centerless lap stock within plus or minus 2 or 3/10ths, as you know. Centerless ground stock within plus or minus 1/2 thousandths is no problem.

PRODUCTION TOLERANCES, CASES

Myers went on, "Perhaps Sandia, in a desire to get super-accuracy, superreliability in components, may overdesign a lot of things that we do. In the testing experience that I have, I have one rolamite unit (keep in mind that this is the device with the Pyrex glass case which we have tested for about three months in proving out our test equipment) where this case is actually broken or cracked right down the middle. It has a thermal crack in it and this device exhibits extraordinary repeatability and reliability. I have never seen it fail, I have never seen it differ outside the tolerance rating on the g closure of about 0.05 g, so it is 1 percent accurate and it is reliable. I bring the point up because perhaps we don't need these accurate cases.

"I think this is true and on commercial devices especially. The tolerances don't have to be held--except when you start considering pumpers, either gas or liquid, then tolerances do get to be a problem. If you don't need the tolerances, don't use them. Get good repeatability--that is a good point. The mandrel material may be plastic; so far it has worked pretty well in the experiments that have been conducted. If the tolerances are liberal enough, you could use the melt-away or throw-away type of electroforming mandrels; that is what we are talking about here. Make them out of plastic and coat them with silver or something to go on the plate; melt or push out the plastic, throw it away."

COMMERCIAL PRODUCTION

A general discussion of rolamite's commercial potential reached beyond its use as laboratory technology. Used for subcomponents of commercial products, the whole rolamite assembly would cost cents to a dollar. Since one of rolamite's attractive features is that it can generate forces and operate with less than perfect manufacture, participants were interested in using fairly rough rollers, extruded cases, and bands that would be cut off on a slitting machine. One manufacturer said, "I am convinced when we are talking tens of thousands of units in production, that rolamite units could be made as a type of device for less than a dollar apiece."

OPERATING CHARACTERISTICS AT HIGH TOLERANCES

However, discussion did point out that much compromise for commercial production could introduce higher side loads. Tolerances must also be maintained for high numbers of cycles of operation.

RELIABILITY OF LOW-COST UNITS

Rolamite is not unique insofar as manufacturing processes are concerned. All design considerations should be brought into the choice, whether it is rolamite or something else; it will take its place among the available routes of design just like anything else.

In a question directed to John Ford, a participant asked, "Could very low-cost units be built, in your experience, so that we could still expect reliabilities as high as 95 percent? Could we put these up in a parallel series combination to achieve an over-all reliability?"

Mr. Ford replied, "I think rolamite is adaptable to very cheap manufacturing techniques as long as you don't have to have very close tolerances of the band. I think there are ways of making the case and rollers cheaply. I would say that in all probability you could make the rolamite device cheaply for high reliability.

* * *

ASSEMBLY

The workshop recognized that a man in the field cannot easily replace a band or part of a unit. The time involved in removing the silastic and reconditioning the system for reassembly is too high. Destroying the unit completely and going to a new one is not unique to rolamite devices.

There are ways of designing the band to be extremely simple to put in commercial devices.

BAND PREPARATION FOR ASSEMBLY

In the second generation MC2472, Sandia has been stiffening the ears on the band. They are using 7-mil-thick stainless steel, about 60/1000 wide, that will be bonded to the 1-mil beryllium copper band material, specifically to stiffen the end tabs. To line up the ears so that they are exactly 90 degrees, they created a simple fixture that will match up the materials; then we put the band in a press, heat it up, and let it set. The laminant lay-up table was not suitable because this material has a tendency to "walk."

BONDING

Sandia reported good shear retention, and good shear bond between the stainless and beryllium copper with BR-1000, but it peels off very easily. This may cause us to resort to spot-welding.

ETCHING BONDED MATERIALS

Bonding does not affect etching, because ammonium persulfate does not attack the stainless. Beryllium copper can be etched as necessary, and the stainless steel then sheared off.

ETCHING A TAB FOR HOLDING BAND TENSION

To hold tension in the band, Sandia described a scheme of etching a tab out of the band. This tab will move out over the roller and will actually attach to a coil spring to keep the system under tension and in the right geometry. In the case of a first rolamite with the stainless steel band, there was an etched spring in the band itself. In the second, it is a coil spring pulled out around a minor diameter in the roller and attached to the end cap with the precision coil spring. A reduced diameter with the tab is needed primarily for clearance. If the tab is broken out, around the minor diameter, tension can be kept on the system without any interference problems. The coil spring was used because differentials in forces made such a design preferable to having it etched out in the spring system.

To avoid a tear problem in this design, Sandia is coating the tab area of the band with about 1/2-mil nickel, and etching through from the back side. Nickel over a wide area will strengthen the tab junction and keep it from tearing out.